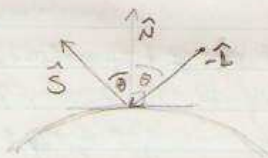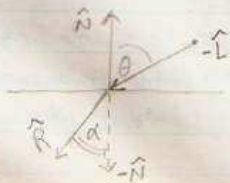# Light Reflection for Ray Tracing

When light hits a boundary (a change in the refractive index), two things can happen: reflection + refraction. For reflection, some portion of the incident light bounces back off the surface at an angle equal to the incident angle. More specifically, the vector of the outgoing light is the reflection of the inverse of the incoming light vector, reflected around the vector normal to the surface at the reflection point.

$\hat{N}$ is the smooth-surface normal
$\hat{L}$ is the inverse of the incoming light vector
$\hat{S}$ is the reflection, which is the rotation of $\hat{L}$ around $\hat{N}$.

For refraction, a portion of the light enters the surface, at an angle different to the incident angle (i.e., the light bends).

This bending occurs because the light changes speed as it enters the medium, and the edge that enters first changes speed first. It is like turning one wheel faster than the other.

So there's a little background. Now lets look at what light looks like coming off a surface, so we can figure out how to render it.

Rendering an opaque point usually comes down to 3 light components: ambient, specular, & diffuse. We'll save ambient for last because it's least interesting.

Specular Reflection

Specular reflection is the kind of reflection we just looked at, where it bounces off the surface at an equal and opposite angle. This is mirror-like reflection that we naturally expect.
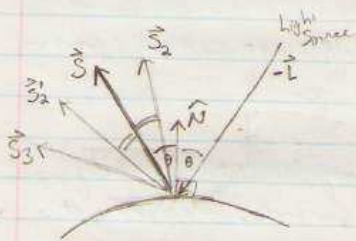
Specular reflection gives us specular highlights, those little bright spots you see on glossy & shiny surfaces. These highlights are actually just the reflection of the light source.

However, these highlights are often blurry & spread out. This is because most surfaces aren't perfectly smooth, even polished surfaces. In reality, the surface is made of lots of tiny subsurfaces that aren't perfectly aligned. Usually, the normals for each of these have a gaussian distribution whose average is the "smooth normal", that is, the normal vector for the idealized smooth surface.

The more these microsurfaces vary (i.e. the greater the standard deviation), the more the specular reflection is smeared out, meaning it's less concentrated (hotter, brighter and more spread out), & the less "clean" the reflection is.

For an ideal smooth surface, light strikes the surface + bounces off
at the opposite angle. If your eye isn't in the path of
this reflection, you won't see it. But for real surfaces, these
non-aligned micro-surfaces are going to cause some of the light
to be reflected back to the eye, even if it's not at the mirror
angle to the light.

Because of the gaussian distribution of the microsurfaces,
you'll get the most reflection back in the mirror direction,
and a normal distribution over other angles.

The most light is reflected at
the smooth-surface spectral reflection
vector $\vec{S}$. Eyes positioned along
$\vec{S}_1 + \vec{S}_2$ (each at equal angle to $\vec{S}$)
will get less light reflected (but both
will get about the same amount as each other,
since everything in this case will), and $\vec{S}_3$, at a
greater angle to $\vec{S}$, will get even less.

This variation can be approximated by raising the cosine of
the angle between the spectral reflection vector ($\vec{S}$) + the
vector from the point of reflection to the eye, to some large
power. The larger the power, the shinier the object: a tighter,
more intense spectral highlight.

Many materials reflect all frequencies of light about the
same, and so the color of spectral highlights is the color of
the incident light, and is not related to the color of the material.
That's why spectral highlights look white, no matter the color of
the object.

Metals, on the other hand, usually reflect only certain wavelengths, which is why specular reflections on copper & bronze, for instance, look coloured (the color of metal).

Diffuse Reflection

If it was only specular reflections we could mention, we wouldn't be able to see much of most materials (just the specular highlights, and maybe a bit of ambient light), and most materials would have no color.

Fortunately, that's not the case. We haven't covered refraction yet.
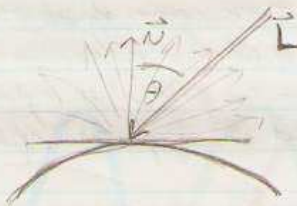
The penetration is not refracted

While a portion of the light is usually reflected (specularly), a portion also penetrates into most surfaces. It doesn't get far; for opaque surfaces, the penetrating light reaches another boundary in the internal structure of the material, and when it does, it reflects off it (really it's the same thing, some reflects, some refracts). And so the light bounces around for a little bit inside the surface. Eventually, it will probably find its way back out, but by then it's at a random angle compared to the incident angle.

This refraction is also what gives most materials most of their color; different frequencies are absorbed instead of passing through, so only certain frequencies come back out.

Simple diffuse reflection assumes an equal amount of light reflected in all directions w/in the hemisphere surrounding the (smooth) surface normal.

Uniform reflection like this is called "Lambertian" reflection & is a good approximation for most materials.

Because of this, it doesn't matter what angle you view from (unlike spectral reflection). What it does depend on is the incident angle of the light. In essence, the steeper the angle (to the normal), the more surface area the light is spread over, so the less bright the reflection. For Lambertian reflection, we usually just make the intensity of diffuse reflection proportional to the cosine of the incident angle
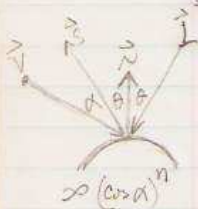

Ambient Reflection

Ambient reflection is a convenient cheat we use in rendering to account of the fact that light bounces at random directions off of everything. The result is that a small amount of light is present pretty much everywhere and going in pretty much every direction from pretty much every point. This ambient light lets us see things that are in shadow w/ no direct illumination.

For rendering we pretty much always assume this ambient light is uniformly distributed in every direction & over the entire space. Ambient light exhibits diffuse reflection; remember,

$\longrightarrow$

specular highlights on reflections of light sources; with ambient light, there is no specific light source.

However, because ambient light comes equally from all directions, the diffuse reflection doesn't take any angle into account; its the same in all directions regardless of its orientation to any light sources.

Summary

$\propto (\cos\alpha)^n$

- Specular reflection is proportional to the intensity of the incident light, & the cosine of the viewing angle, raised to a power. The smoother the surface, the higher the power. Most materials, other than metals, reflect all frequencies equally.

$\propto \cos\theta$

- Diffuse reflection is proportional to the intensity of the incident light, & to the cosine of the incident light angle. Color of reflection is the color of the material.

- Ambient reflection is constant absolutely everywhere, & is the color of the material.